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On the Comparative Advantage of U.S. Manufacturing: Evidence from the Shale Gas Revolution

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Abstract

This paper provides the first empirical evidence of the newly found comparative advantage of the United States manufacturing sector following the so-called shale gas revolution. The revolution has led to (very) large and persistent differences in the price of natural gas between the United States and the rest of the world owing to the physics of natural gas. Results show that U.S. manufacturing exports have grown by about 6 percent on account of their energy intensity since the onset of the shale revolution. We also document that the U.S. shale revolution is operating both at the intensive and extensive margins.

Keywords: manufacturing, exports, energy prices, shale gas

JEL Codes: Q33, O13, N52, R11, L71

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Our 100-year supply of natural gas is a big factor in drawing jobs back to our shores. Many are in manufacturing-the quintessential middle-class job. During the last decade, it was widely accepted that American manufacturing was in irreversible decline. [...] And today, American manufacturing has added more than 700,000 new jobs. It's growing almost twice as fast as the rest of the economy. And more than half of all manufacturing executives have said they're actively looking at bringing jobs back from China.[1]

- President Barack Obama

We came to the conclusion this -the shale revolution- will be a sustainable advantage for the United States. That is why we are comfortable making an investment.[2]

- Hans-Ulrich Engel, BASF North America Chief

1 Introduction

The United States is in the midst of an energy revolution. It all started in the 1980s with the independent company founded by the late George Mitchell. The company had been experimenting with application of different techniques of hydraulic fracturing-a well stimulation technique in which rock is fractured by a hydraulically pressurized liquid-of the Barnett Shale of Texas, eventually finding the right technique to economically extract the natural gas in the formation. The combination of hydraulic fracturing and directional drilling-the practice for drilling non vertical wells-was then widely adopted by the gas industry in turn spawning a natural gas boom in North America in the 2000s. The surge in the production of shale gas has made the United States the largest natural gas producer in the world. As exemplified by the above quotes, the shale gas revolution has since then sparked an academic and policy debate on the potential implications of such revolution on the U.S. economy. Anecdotal evidence from news reports indicate that the dynamics in capacity expansions have accelerated as a result of U.S. shale, with non U.S.-based chemical producers having recently announced USD 72 billion worth of investment in new plants.[3]

The present paper provides the first empirical evidence of the newly found comparative advantage of the United States manufacturing sector following the so-called shale gas revolution. The revolution has led to (very) large and persistent differences in the price of natural gas between the United States and the rest of the world owing to the physics of natural gas. Results show that U.S. manufacturing exports have grown by about 6 percent on account of their energy intensity since the onset of the shale revolution. We also document that the U.S. shale revolution is operating both at the intensive

[1]Excerpt from remarks at Northwestern University on October 2, 2014. See http://www.whitehouse.gov.

[2]Excerpt from an interview with Bloomberg News on June 27, 2014, http://www.bloomberg.com

[3]See http://www.bloomberg.com.

and extensive margins.

Natural gas has the lowest energy density, measured by the amount of energy stored in a given unit of matter, among fossil fuels (petroleum products, natural gas, and coal).[4] Even with pipelines, long distance trade of natural gas from the point of extraction becomes uneconomical quickly, as the gas in the pipeline needs to be cooled and pressurized, which uses up significant amounts of energy. Liquefaction at origin and re-gasification at destination are the only other means for long distance trade. However, the laws of physics governing liquefaction and re-gasification, imply an exogenously given lower bound on the transport cost. This suggests, that natural gas markets are much less integrated compared to markets for other fossil fuels.

Given the physical limits to directly trade natural gas, its not surprising that, following the shale gas production boom in the U.S., natural gas prices have fallen sharply in recent years and are effectively decoupled from those in the rest of the world.[5] For instance, in August 2014 U.S. natural gas price sold 4 dollars per million British thermal units, compared to 10 dollars in Europe and close to 17 dollars in Asia. Cheaper energy prices in the U.S. relative to the rest of the world could have dramatic consequences on the manufacturing sector. For instance, the petrochemical industry and other industries that are able to utilize natural gas will pass these lower input prices downstream through the value chain. Figure 1 show that the rise in U.S. manufacturing exports weighted by their energy intensity mirrors the rise in price gap between the U.S. and the rest of the world. In contrast, the energy content of U.S. imports has roughly stagnated.[6] This paper aims at investigating systematically the consequences of lower natural gas prices in the United States on the external competitiveness of U.S. manufacturing.

A burgeoning literature has attempted to document the economic consequences of lower energy prices and specifically natural gas prices following the shale gas revolution. Existing literature typically focuses on localized economic effects of the shale gas boom in turn exploiting within-country variation in natural gas prices as opposed to between-country variation. These papers study the direct effects of resource extraction activity on local economic structure and are very much related to the literature on Dutch disease.[7] Available estimates indicate that the energy boom in the U.S. has

[4]Natural gas is also the cleanest source of energy among fossil fuels and does not suffer from the kind of environmental liabilities potentially associated with nuclear power generation.

[5]The U.S. shale revolution also led to a substantial increase in oil production. As stated earlier, oil does not however share the physical properties of natural gas in turn oil markets are much more integrated than natural gas markets. While both the shale oil and gas booms have led to lower world average energy prices compared to what they would have been without these booms, the shale gas boom in particular has increased the dispersion in regional prices.

[6]Appendix Figure A2 documents the tight relationship between shale gas production and the growing energy intensity of exports, while Appendix Figure A3 documents a similar pattern when considering energy intensive sector trade share not based on weighting by the input-output table estimated energy intensities, but by focusing on a set of three digit sectors that are particularly energy intensive.

[7]See for example Allcott and Keniston (2013), Fetzer (2014) and Agerton et al. (2014) in the context of the US and Aragón and Rud (2013), Sachs and Warner (1995), van Wijnbergen (1984) in context of developing countries.

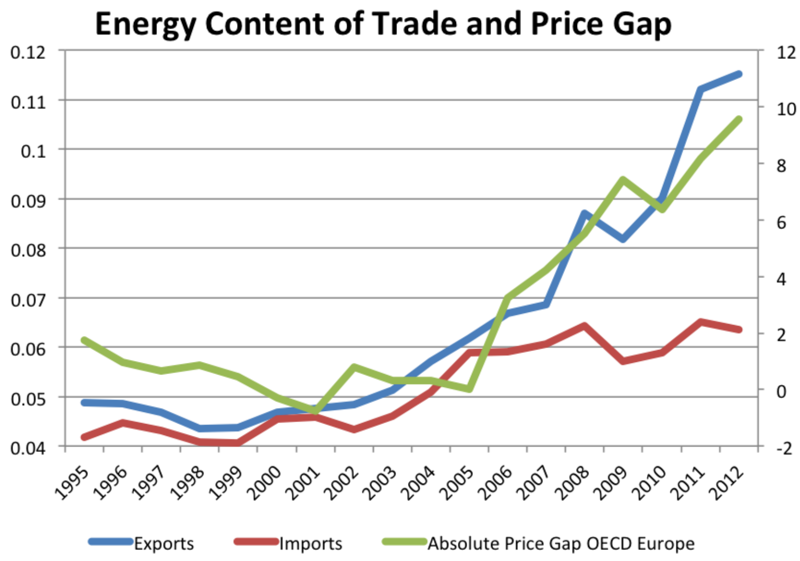

Figure 1: Evolution of the Energy Content of Imports and Exports.

Notes: On the left axis the figure presents U.S. manufacturing exports and imports weighted by their energy intensity according to energy cost shares derived from the 2002 U.S. input-output table. The right axis presents the industrial use natural gas price gap between the U.S. and OECD Europe.

created between 400,000 and 600,000 new jobs over the last 10 years (see Agerton et al., 2014; Fetzer, 2014; Boudiaf and Yegorov, 2012). Hausman and Kellogg (2015) find that the shale gas revolution has led to an increase in welfare for natural gas consumers and producers of $48 billion per year.[8] Energy price variation within the U.S. may help understand why local booms may not induce a structural shift away from manufacturing (see Fetzer, 2014). These differences in local natural gas prices could however be thought as relatively smaller and may prove to be temporary compared to differences between the United States and the rest of world. This paper complements this literature by focusing on the trade implications of the shale revolution, in addition to using data on investment in new and expanding plants at the county level. To the extent of our knowledge, this paper is the first to do so.

This paper also relates to the strand of literature investigating the decline in U.S. manufacturing beginning in 2001 (see Figure A1). This strand of literature focuses on the employment implications of U.S. trade liberalization vis-a-vis China. Implicitly that amounts to testing the importance of China's comparative advantage in terms of lower labor costs. For instance, Pierce and Schott (2012b) find evidence for the link between

[8]Two recent studies have exploited sector level data to isolate the effect effect of lower energy prices on the manufacturing sector but not on trade. Using industry-level data, Melick (2014) estimates that the fall in the price of natural gas since 2006 is associated with a 2.3 percent increase in activity for the entire manufacturing sector, with much larger effects of 30 percent or more for the most energy-intensive industries. Celasun et al. (2014) find that a doubling of the natural gas price differential in favor of the home country would increase manufacturing industrial production by 1.5 percent.

the sharp drop in U.S. manufacturing employment and a change in U.S. trade policy that eliminated potential tariff increases on Chinese imports. Harrison and McMillan (2006) using firm-level data find that off-shoring by U.S. based multinationals is associated with a quantitatively small decline in manufacturing employment.[9] Less attention has however been paid to the recent recovery in the U.S. manufacturing sector and the change in composition in U.S. exports. Our contribution to this literature is to document systematically evidence of a noticeable turn around in U.S. manufacturing exports owing to U.S. newly found comparative advantage in terms of lower natural gas prices. We argue that the difference in natural gas prices between the U.S. and the rest of the world is not transitory, but rather persistent in nature due to the physical properties of natural gas and the distance to foreign markets. The sizable gap in natural gas prices between the U.S. and the rest of the world might to some degree help limit U.S. comparative "dis-advantage" in terms of labor costs.

Our paper also relates to the pure theory of trade that emphasizes the role of differences in the availability of productive factors in explaining trade. This dates back at least to Rybczynski (1955) theorem that states that when the amount of one factor of production increases, the production of the good which uses that particular factor of production intensively increases while the good that uses that factor less intensively will decrease, at a given relative factor price. Rybczynski's analysis was originally developed in a closed economy setting but was prominently extended in the two-country Heckscher-Ohlin-Vanek (HOV) framework. In that setting, an increase in a specific factor endowment in the home country may lead that country to export more of the good that is intensive in that factor and the foreign country to decrease its export of that very same good. More recently, Bernard and Jensen (2007) allows for a more complex understanding of the importance of factor endowment in a framework derived from new trade theory allowing for both monopolistic competition and heterogeneous firms (e.g. Melitz, 2003; Helpman et al., 2004).[10] Another relevant area of research in trade extends the relevance of comparative advantage to intangible factors. For instance, Nunn (2007) find that countries with good contract enforcement specialize in the production of goods for which relationship-specific investments are most important.[11].

Empirical tests of theories predicting the factor content of trade have been mixed. However, Davis and Weinstein (1998) show that with a small number of amendments

[9] Autor David H. and Hanson (2013) analyze the effect of rising Chinese import competition between 1990 and 2007 on US local labor markets. The authors find that rising imports cause higher unemployment, lower labor force participation, and reduced wages in local labor markets that house import-competing manufacturing industries. Import competition explains one-quarter of the contemporaneous aggregate decline in US manufacturing employment.

[10] Bernard and Jensen (2007) framework simultaneously explains "why some countries export more in certain industries than in others (endowment-driven comparative advantage), why nonetheless two-way trade is observed within industries (firm-level horizontal product differentiation combined with increasing returns to scale) and why, within industries engaged in these two forms of trade, some firms export and others do not (self-selection driven by trade costs)". In this paper, we exploit sector level data to document the former and also document the extensive margin of trade including using county level data.

[11] See also related work by Berger et al. (2013), Guiso et al. (2009) and Bahar et al. (2014).

including technical differences and a failure of factor price equalization the HOV model perform relatively well in that countries export their abundant factors and do so with the right magnitudes.[12] In other words, trade theory reliability predicts that a country facing relative abundance in one factor of production such as shale gas in the U.S. would indirectly export that factor by exporting more of the goods that are intensive in that specific factor. [13] In this paper, we argue that the U.S. shale gas revolution provide a quasi-natural experiment to test the importance of factor endowment in shaping patterns of U.S. trade.

To do so we systematically investigate the response of U.S. manufacturing exports to the plausibly exogenous variation stemming from the interaction between the differences in natural gas prices between the U.S. and the rest of the world and the energy intensity of manufacturing sector exports. Estimation results of gravity models show that the U.S. manufacturing exports have grown by about 6 percent on account of their energy intensity since the onset of the shale gas boom. Using a data-set of investment in new and expanding manufacturing plants, we also document that the U.S. shale revolution is operating both at the intensive and extensive margins with new manufacturing sector capacity being added in the energy intensive industries.

The remainder of the paper is organized as follows. Section 2 discusses the physics of natural gas and its implications for trade costs. Section 3 describes the various data-sets used and lays out the empirical strategy. Section 4 presents the main results. Section 5 discusses robustness checks. Section 6 concludes.

2 The Physics of Natural Gas

Differences in regional natural gas prices are fundamentally determined by the laws of physics through the bearing the latter have on both transformation and transportation costs. For pipeline transportation, the cost relates to the frictions that arise as natural gas travels through pipelines. Natural gas transportation via pipelines between the U.S. and other major markets such as Europe and Asia is however not a viable option, due to the long distance natural gas would need to travel. This requires re-compression along the way due to the natural friction, which is not possible beneath the sea surface given existing technology. To be traded, U.S. natural gas would thus need to be shipped and that requires liquefaction. For liquefaction of natural gas, the costs arise due to the work required to compress and cool down natural gas to achieve a phase change from gas to liquid. This occurs at temperatures of around -160 degrees celsius (-256 degrees Fahrenheit). The gas is then compressed to only 1/600th its original volume. Natural gas has a heating value of around $Q = 890kJ/mole$. The minimum energy required

[12] For empirical test of HOV trade theory see also Harrigan (1995) and Harrigan (1997), Bernstein and Weinstein (2002) and Maskus and Webster (1999) among others.

[13] Debaere (2014) provides empirical evidence that water is a source of comparative advantage and that relatively water abundant countries export more water-intensive products. He finds that water contributes significantly less to the pattern of exports than the traditional production factors labor and physical capital.

to liquefy natural gas is implied by the first law of thermodynamics. This minimum energy requirement has two components. First, there is an energy requirement in order to cool down natural gas. The amount of energy required for that is dictated by the specific heat of natural gas. The specific heat of substance measures how thermally insensitive it is to the addition of energy. A larger value for the specific heat means that more energy must be added for any given mass in order to achieve a change in temperature. For natural gas that constant is given by $c_p = 2.098\frac{J}{g}$, meaning that 2.098 Joules of energy are required to achieve a 1 degree change per gram of natural gas at constant pressure. The second component of the energy requirement is the energy required to achieve a phase change. A phase change consists in the change in physical properties from gaseous to liquid and then to solid. A phase change does not involve a change in temperature but rather a change in the internal energy of the substance. The amount of energy required to achieve a phase change from gaseous to liquid is given by the substances latent heat of vaporization, for natural gas that is $\Delta H_v = 502J/g$.

From the above, we can compute the implied minimal energy required to cool down natural gas and achieve a phase change as follows:

$$Q_{l,min} = W_{l,min} = c_p \Delta T + \Delta H_v$$

.

The minimal energy required to liquefy natural gas from 20 degrees to -160 degrees is 14.1 kJ/mole. This does not seem that significant in relation to the heat content of 890 kJ/mole, accounting for only 1.6% of the heat content. However, the actual work required is a lot higher since the energy required to cool down and achieve the phase change is obtained from other physical processes involving the burning of fuel. These processes are far from achieving a 100% energy conversion efficiency. The actual work required can be expressed as:

$$W_l = \frac{W_{l,min}}{\epsilon_l \times \epsilon_w}$$

,

where ϵ_w is the energy conversion efficiency of converting methane to electricity and ϵ_l is the efficiency factor for conversion to liquids. These shares are significantly lower than 1. The Department of Energy estimates that $\epsilon_w = 35\%$, while ϵ_l may range between 15% - 40% (see Wegrzyn et al. (1998)). This suggest that the energy costs for liquefaction can range anywhere between 100kJ - 268 kJ, suggesting energy losses range between 11.2%-30% from the liquefaction process alone.

In addition, there are losses associated with the re-gasification process; furthermore, there are costs for transport, storage, and operating costs along the whole value chain. All these accrue in addition to the conversion costs implied by the laws of physics. A recent analysis of a proposed LNG plant in Cyprus suggests that the minimum liquefaction costs are 1.4 times the cost of the natural gas feedstock.[14]

The inherent costs associated with transforming and transporting natural gas thus suggest that domestic natural gas prices in the U.S. will remain significantly lower compared to Europe and Asia in the foreseeable future. In the following, we investigate systematically whether the shale gas revolution is a source of comparative advantage for U.S. manufacturing. The next section presents the data used and the main empirical specifications.

3 Data and Empirical Specification

To explore the effect of the shale revolution on U.S. trade, we proceed in three steps. First, we study the overall effect of the revolution on manufacturing exports and imports. Second, we explore the extensive margin of the trade effect, by examining whether U.S. manufacturing exports and energy intensive ones in particular, have reached newer trading partners. Third, we examine the extent to which the effect of the shale revolution on U.S. trade has been channeled through the addition of new production capacity.

3.1 Exports and Imports

The trade data are from Schott (2004). In addition, we use concordances provided by Peter Schott and the Bureau of Economic Affairs to match input-output tables data to the foreign trade harmonized codes. The resulting data-set used in our main analysis of U.S. exports is a balanced panel of five digit sector level data using North American Industry Classification System (NAICS) mapped to destination countries. There are 167 manufacturing sector codes at the five digit level. There are 233 destination countries and 17 years of data from 1996-2012. Overall this amounts to 661,487 observations. Not all observations have positive trade, in which case a zero is reported.[15] That allows us to study the extensive margin of trade as well, i.e. trade occurring for new products and country pairs.[16]

The dependent variable in our specifications is either, the level of exports or the

[14]See Natural Gas Monetization Pathways for Cyprus, MIT Energy Initiative, http://mitei.mit.edu.

[15]The main results presented in this paper are very similar, when we estimate Poisson models to account for the fact, that about 38% of the observations are zero (See Silva and Tenreyro (2006)). These results are available from the authors upon request.

[16]See Appendix A.1 for details. Note that the trade data can be matched with the 7 digit NAICS industry classification level, however, the best concordance between the six digit Input-Output tables and the trade data is achieved at the 5 digit NAICS sector classification. The trade data also contains information on U.S. customs district, where the export data was recorded. We remove this dimension, primarily to reduce the dimensionality of the balanced panel. Note that, at the five digit sector, there are 167 five digit industries, while there are 233 countries for 17 years of data. This renders the sample already substantial with roughly 661,487 observations. If we add the customs district origin dimension, this would result in a balanced panel with around 30 million observations. Out of these, only around 4 million observations are non-zero on either imports or exports side. Appendix A.3 explores the trade effects when accounting for the customs origin district on an unbalanced panel to exploit within US natural gas price differences.

logarithm of exports or a dummy that takes that value of 1 if there is non-zero trade following three consecutive years of no trade and 0 otherwise. We estimate two main empirical specifications that are introduced in turn.

Non-Parametric Estimation We first focus on the non-parametric specification which takes the following form:

$$X_{ijt} = \alpha_{it} + b_{ij} + \sum_{t} \gamma_t \times E_j + \epsilon_{cijt} \tag{1}$$

This specification controls for destination specific time fixed effects α_{it}, with i indicating the destination, while t is the time-dimension. In addition, we control for five digit sector code j by destination i fixed effects b_{ij}. The trade-pair specific time fixed effects α_{it} controls for time varying shocks that are specific to the trade-pair. Some examples of variables that would be perfectly collinear with these fixed effects are general demand shifters, such as annual GDP, population, and exchange rates. The second set of fixed effects controls for general trade pair and product specific demand shifters. These would capture any time-invariant factors that affect say demand from China for U.S. energy intensive exports. These fixed effects capture for instance bilateral distance and other time-invariant sector specific trade frictions. All identifying variation is thus coming from the variation in energy intensity measured by E_j across sector codes. To construct energy intensity, we choose to use the 2002 Bureau of Economic Analysis Input-Output tables-prevailing before the shale boom-at the five digit NAICS industry classification level. Later input-output tables could also be used, in particular the 2007 version. This is problematic, given the fact that technology coefficients derived from later input-output tables are endogenous and would thus potentially bias our regression estimates (see e.g. Morrow and Trefler, 2014). [17] We distinguish energy consumed from all sources (in particular electricity and natural gas); alternatively, we focus exclusively on natural gas consumption. In both cases, energy can be consumed directly and indirectly, through intermediate goods consumption. Using overall energy intensity allows us to account for potential substitution effects between natural gas and other energy sources.[18] Using only natural gas consumption allows us to get closer to the source of the comparative advantage. Table 1 provides an overview of energy intensities by their input-output table shares at the three digit sector level; in addition, the size of sectors relative to the overall economy is reported. The most energy intensive sectors are, not surprisingly, Petroleum and Coal Products Manufacturing, Primary Metal Manufacturing, Non-metallic Mineral Product Manufacturing and Chemical Manufacturing.

We are interested in the evolution of the coefficients γ_t over time; positive coefficients would indicate that export of energy intensive products is growing stronger,

[17] The details of the construction are discussed in appendix A.2.

[18] This help allay some of the concerns that arise because we use input-output tables related to pre-shale boom era for a specific year implicitly assuming that the production technology is fixed.

relative to non-energy intensive sectors. The results from the non-parametric exercise are presented graphically. The non-parametric analysis highlight the evolution of trade volumes accounting for the energy intensity of the respective products. The coefficients are difficult to interpret but could help confirm the strong relationship with the emerging natural gas price gaps. In order to ease interpretation, we estimate the same specification parametrically.

Parametric Estimation In the non-parametric specification, we allowed the estimated coefficient γ to change over time. We can also rely on time-variation coming from a measure of the endowment shock which allows us to estimate a single coefficient. In table form, we present evidence from such a parametric approach. The specification is as follows:

$$X_{ijt} = \alpha_{it} + b_{ij} + \gamma \times E_j \times \Delta P_t + \epsilon_{ijt}, \tag{2}$$

The fixed effects are as before, however, now we exploit the time-variation in the price gap in natural gas between the U.S. and the rest of the world, as captured in P_t. The rest of the world prices are proxied by the average price of natural gas in OECD Europe countries, constructed by the International Energy Administration. As discussed earlier, the price differences arise due to the shale gas production boom, which has been widely unanticipated. The price differences cannot be arbitraged away directly, due to the inherent physical properties of natural gas discussed in the previous section. Pure trade theory predicts that the U.S. would export natural gas indirectly through value added in the form of processed goods for which trade costs relative to the value of the good are sufficiently lower. Using the price gap as an interaction term makes it particularly easy to interpret the coefficients. In the main tables, we focus on US exports to all countries. However, we also restrict the analysis to OECD countries where we do have trading country natural gas price data. While the OECD countries are only 28 countries out of a total of 233 destinations, they account for more than 62 % of the value of all US exports in 2005.[19] For this subset, the interaction term in the above specification will be $E_j \times \Delta P_{it}$. We would not expect the estimated coefficients to change dramatically using a more comprehensive set of price gaps. Indeed, the variation in the price gaps that is relevant is not driven by prices changing elsewhere in the world, but rather by U.S. prices dropping dramatically. Alternative measures to account for the U.S. shale gas boom could be used, such as levels of shale-gas production or the estimated level of reserves in the interaction terms. Our results are robust to using these variables, yet, the coefficients are much more difficult to interpret. To explore the underlying mechanisms driving export expansion, we separate the intensive- and extensive margins. To study the intensive margin of the effect of the shale revolution on

[19]That observation is consistent with Easterly and Reshef (2009) who document the remarkably high degrees of concentration in manufacturing exports. In other words, manufacturing exports tend to be dominated by a few "big hits", which account for most of export value.

U.S. trade, we focus the analysis on trade pairs that had been trading a specific good throughout the sample period running from 1996 to 2012. In practice, we estimate the specification (1) on this subset. To study the extensive margin of trade, we use an analogous specification except that the dependent variable is a dummy variable that takes the value of 1 if there is non-zero trade for product j to a destination country i at time t following three consecutive years of no trade. The second important margin that we study is whether the manufacturing sector is actually expanding in real terms, that is through the construction of new manufacturing capacity inside the U.S. We do so by exploiting plant level construction data.

3.2 Capital Expenditure

To explore whether new production capacity is being added, we estimate two specifications, which are analogous to the one used earlier for exports. The main non-parametric specification is:

$$D_{cjst} = \alpha_{cj} + d_{st} + \sum_t \gamma_t \times E_j + \epsilon_{cjst}, \tag{3}$$

where $D_{cjst} = 1$ if a sector j invests in an investment project in year t and county j in state s. We perform that analysis lumping capacity additions and new plants together. We also separately estimate these specifications focusing on new plant construction alone. The data we use is proprietary data on plant expansion and new plants collected by Conway. Conway collects data for capital expenditure and they are considered to have most extensive U.S. coverage.[20] For a project to be included in the data set, it needs to meet at least one of the following criteria: (1) the project cost should be at least USD 1 million, (2) covering at least 20,000 sq. ft. or (3) create employment for at least 50 people.

The data is available at the zip code level and provides the number of jobs created, and the size of the capital expenditure as well as the NAICS industry classification. We perform the analysis at the county level rather than the zip code level. Since we are not relying on the spatial variation, going to that finer level would not add much to the analysis. Furthermore, not all sectors are classified up to the 6 digit industry code. However, 98% of projects provide NAICS codes at least at the 3-digit industry level. Hence, we construct the panel at that level.[21]

[20] Some subsets of the data has been used in previous research studying the impact of capital expenditures in the manufacturing sector on local economic structure (See Greenstone et al. (2010), Greenstone and Moretti (2003)).

[21] For the robustness, we also construct the panel at the five digit industry level. This comes at a cost, as we need to assign investment projects, that were classified only at the three digit NAICS level to a five digit industry code. That requires us to make some assumptions. We try to find the best matching five digit NAICS industry code, based on matching the textual description of the capital expenditure project to the five digit NAICS sector description. Note that at the 5 digit industry level, the panel becomes rather large, since there are 167 five digit sectors, rendering a sample with around 5.8 million observations, out of which the vast majority are zeroes.

As before α_{cj} are county by 3-digit industry fixed effects; while d_{st} are state by year fixed effects. That regression will yield a set of coefficients that can be plotted. A parametric approach is presented in tables, where we use the time variation from the price gap between the U.S. and OECD Europe.

$$D_{cjst} = \alpha_{cj} + d_{st} + \gamma \times E_j \times \Delta P_t + \epsilon_{cjt} \tag{4}$$

In addition to this dummy-variable specification, we also present results with the number of projects, the level of investment and the number of jobs created. Furthermore, we distinguish between the results stemming from new manufacturing plants versus capacity expansions, to explore whether we are only capturing additions to existing capacity.

The key concern with this specification is that we may be capturing the direct effects of the resource boom in addition to the extensive margin investment response due to a built-up to export natural gas through value added. While we can not entirely rule that out, constraining the sample to the counties that do not have shale resources, we obtain qualitatively similar results.

The next section presents the main results on the export response to the shale gas revolution. This is then further refined into the margins of response: intensive margin of trade and measures of the extensive margin of trade, along with a study of manufacturing sector capacity additions.

4 Results

4.1 Exports/Imports

Results showing the non-parametric evolution of exports for energy intensive sectors over time are presented first. That non-parametric approach implies that we refrain from imposing structure. Figure 2 presents non-parametric specification results. The estimated coefficients for import as well as exports are plotted out.

It should be noted that the interaction for the import-specification is somewhat problematic as it does not reflect the energy intensity of production sectors in the rest of the world vis-a-vis the US. Instead, it assumes that the rest of the world has access to the same production technology as the U.S. as represented by the respective energy intensity. However, one would not expect the energy intensity for identical industrial processes to be exhibiting significant differences, especially for the set of OECD countries.

The coefficients from the non parametric estimation suggests that exports for energy intensive sectors have grown disproportionally, while imports have stalled. The coefficient for 2012 indicates that exports have grown by 2.5 log points for a sector that uses only energy as input. It is not straightforward to translate this non-parametric estimate into a proportional change due to the complications of interpreting interacted dummy variables in such a setup.[22] The key observation is that the growth in exports coincides with the emergence of the natural gas price gaps.

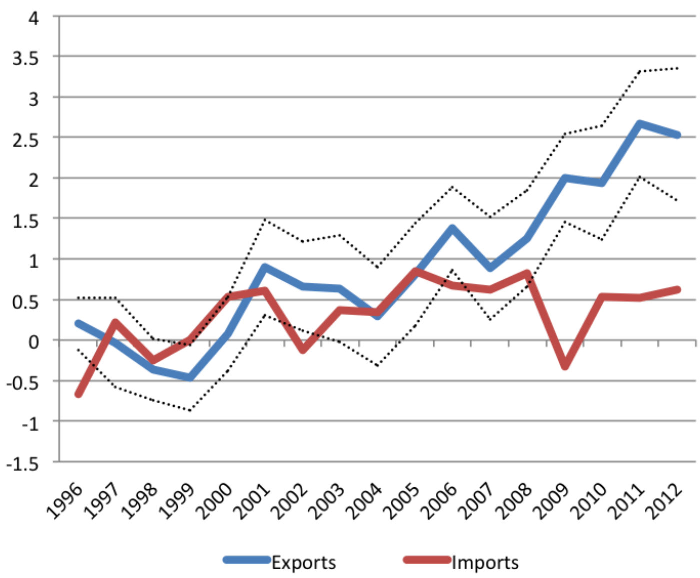

Figure 2: Energy Intensive Industry Export Growth Over Time. The figure presents regression coefficients from non-parametric specification interacting energy intensity with year fixed effects, while controlling for trading country and year fixed effects, three digit industry sector time fixed effects and commodity by trading country pair fixed effects. 95% confidence intervals from standard errors, clustered at the two-digit by destination/ origin region level are presented in dotted lines.

Results from the parametric estimation are presented in this section and allow for a more direct interpretation of the results. Results are presented in Table 2. The dependent variable is the logarithm of the export value. The coefficient on the interaction can be interpreted as a semi-elasticity. The estimated coefficient in column (2) of Panel A implies that a 1 dollar increase in the price gap, increases exports by 21.5% provided that the sector under consideration uses 100% energy as an input (i.e. a sector which only uses energy). For Chemical Manufacturing, which has a total energy cost share of 8.33 %, this translates into an increase in exports of 8.33% $\times$ 21.5% $=$ 1.79% for every dollar that the price gap increases. Given that the price gap has increased to almost USD 10 since 2005, this represents an increase in exports for this sector by 17.9%. Overall, our estimation results show that the U.S. manufacturing exports have grown by about 6 percent on account of their energy intensity since the onset of the shale gas revolution.

As expected, the results using refined measures of the price gap in the other panels of Table 2 are not dramatically different, since the U.S. shale gas boom leaves prices elsewhere unaffected due to the lack of integration of natural gas markets. In Appendix Table A4 we separately analyze imports. No consistent pattern emerges, suggesting that

[22]See Kennedy (1981).

import levels of goods that are energy intensive do not change dramatically in response to the shale gas boom.[23] A core prediction from the HOV framework is that in response to the endowment shock, exports of non-energy intensive goods should fall. This can be tested by interacting the measure of the exposure of the endowment shock with a measure of the non-energy intensity of a particular sector. The main other factors of production are capital and labor.

The results are presented in Table 7. The coefficient on the interaction between energy intensity and the price gap does not change, when we include additional interaction terms capturing the sectors relative labor- or capital intensity. But more importantly, the coefficients on both other terms are negative and significant. This is very much in line with the simple predictions derived from a HOV framework.[24]

4.2 Margins of Trade

In this section, we attempt to separate between the intensive and extensive margins of U.S. trade response to the shale gas revolution.

4.2.1 Intensive Margin

In this section, we focus on country- and sector- pairs for which there has been non-zero trade for the whole time period. That applies to 17,341 out of 39,955 pairs. The results are presented in Table 3. The coefficients are similar to those in the main table; if anything, they are slightly larger suggesting that the bulk of the overall estimated effect is coming from intensive margin expansion of energy intensive trade.

4.2.2 Extensive Margin

In order to ascertain whether the U.S. trade response to the shale gas revolution operates at the extensive margin, we explore whether new trade is occurring on sectors by destination pairs for energy intensive sectors. The dependent variable is a dummy that takes that value of 1 if there is non-zero trade following three consecutive years of no trade and 0 otherwise. The results are presented in table 4. The coefficients associated with the various measures of energy intensity strongly positive. The coefficient in Panel A of column (2) suggest that, for a good that uses 100% energy input, the observed extensive margin increase is 0.33 percentage points. This is a large relative increase of 10.6%, given that such transitions are relatively rare in the data and occur only for 3% of trade pairs.[25]

[23] The assumption here is that the U.S. production technology captured by the input-output table coefficients maps well into the available production technologies elsewhere.

[24] We obtain very similar results when using the further refined measures for the price gap as discussed in the main text. These are available on request.

[25] In Appendix Table A5 we present evidence of the extensive margin of the shale gas revolution on energy intensive imports; no statistically significant pattern emerges.

4.2.3 New Manufacturing Capacity

To further explore the extensive margin of the trade response, we investigate whether expansions or actual new plants are being added especially in the energy intensive sectors.

Figure 3 uses direct energy cost share from the 2002 Input Output tables interacted with a set of year effects. The left hand side here is a dummy that takes the value of 1 if a county in a sector experienced some capital expenditure in a given year, and zero otherwise. The omitted year is 2003 where the capital expenditure data begins. The coefficient pattern suggests that energy intensive manufacturing sectors were more likely to invest in additional and new capacity from 2008 onwards relative to the base year 2003. The coefficients vary a lot more from year to year, but are consistently positive. This suggests that the manufacturing sector is adding new productive capacity in response to the shale gas boom.

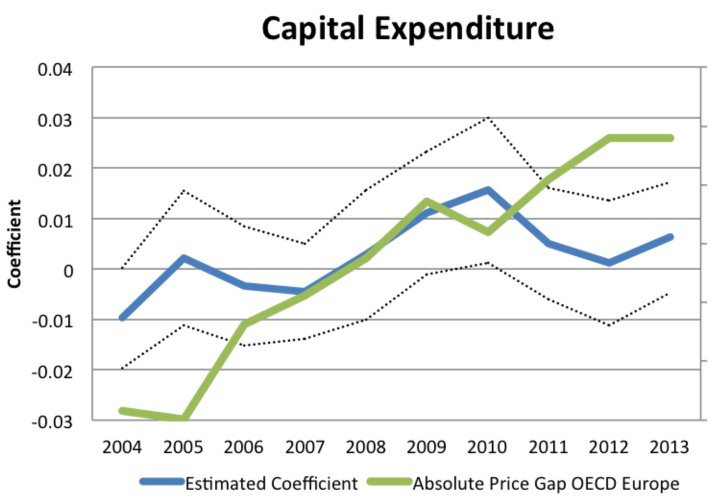

Figure 3: Capital Expenditure and Energy Intensity Over Time

We can further refine these results by studying completely new capital expenditures relative to expansions of existing capacities. We present that in Table 5. Column (1) is a simple linear probability model of whether there has been any capital expenditure in a district and county by industry. The mean of the dependent variable indicates that 2.9% of county-and sector pairs experience some capital expenditure over the whole sample period. The estimated coefficient is 0.109. As the price gap between the US and OECD Europe has increased to USD 10, this coefficient can be interpreted as follows. Given the price gap of USD 10, the likelihood of capital expenditure for an industry that has an energy intensity of 5% would increase by around 1.95%.

The coefficients in columns (2) - (4) are interpreted as semi-elasticities. The results in column (3) indicate that, for an average US manufacturing sector, the increase in the price gap by about USD 10 between the US and OECD Europe has increased investment by 2.67%, ceteris paribus.

The results in Panel B indicate that the results are strongly driven by capital expenditure for completely new investment projects, rather than capacity additions. The share of capital projects that are completely new is a lot lower, around 1.29% of counties experience some completely new capacity expansion. The underlying reason for why these investments occur certainly lies in the expectation that the shale gas boom will lead to a price differentials that will persist for the years to come.

A main concern with this analysis, exploiting variation within the U.S., is that we pick up the direct effects from the shale gas boom. While we can not rule this out as some of the capacity additions documented in the data may be directly related to the Oil and Gas industry, when removing counties where shale deposits lie, we obtain qualitatively similar results. That suggests that we are not solely picking up the direct spillover from the shale gas boom (see Table A7).

5 Robustness

This section explores four main robustness checks namely to measurement of energy intensity, accounting for variation in regional prices within the U.S., the degree to which the shock to comparative advantage may be correlated with a secular trend away from labor intensive to energy intensive manufacturing, and accounting for price differences.

Measure of Energy Intensity Instead of relying on the constructed measure E_j, we can also proxy that measure of energy intensity, by interacting sector dummies with the price gap. That then allows us to obtain an estimate for every sector separately. The estimated coefficients combined with the sectors relative size and the constructed measure E_j, we would then be able to identify the sector that would experience a stronger growth in exports. The specification is as follows:

$$X_{ijt} = \alpha_{it} + b_{ij} + \sum_{j \in J} \gamma_j \times D_j \times \Delta P_t + \epsilon_{ijt} \tag{5}$$

where $D_j = 1$ if a exports between the US and country i at time t fall in three digit sector j.

The results obtained from using this alternative measure of energy intensity are similar to our main results. The results are presented in Table 6. The most striking observation is that, in particular, non-durable chemical processing industries are experiencing strong positive export growth (NAICS sectors 321-327) and energy intensive durable goods, in particular Metal Manufacturing. These results are consistent with the parametric estimates.

U.S. regional variation in natural gas prices As highlighted in Fetzer (2014), regional natural gas price differences could be relevant. In appendix A.3, we present results from a specification using an unbalanced panel with the added dimension of US customs district origin. We map natural gas prices to US customs districts and can augment the analysis of the above specification to include the within-US price differences. The coefficients are smaller, but comparable, as we exploit more variation in natural gas prices.

Accounting for Secular Trend One other concern is that the boom in shale gas production and the subsequent widening of the price differences is correlated with another trend that drives energy intensive exports. Indeed, the existing trade literature emphasises the global trends of labour intensive production occurring in countries with a comparative advantage in labor, while only the capital intensive production remains in developed countries. If energy-intensive sectors are, at the same time, capital intensive, the estimated effects of the shale gas revolution could then be contaminated. Considering that our estimates are virtually unaffected when including additional interaction terms capturing the sectors relative labor- or capital intensity, we can confidently ascertain that our results are not driven by the above mentioned trend (see Table 7).

Accounting for Price Differences Since the estimated regressions include trade value denominated in US dollar, they could be capturing changes in mark-ups and prices in general. This is unlikely to be a concern since the time-fixed effects and the sector by trading partner fixed effects absorb a lot of the characteristics, such as differences in exchange rates. Nevertheless, we can perform the main analysis using a crude proxy of the trade volume in real terms, by studying the overall weight of all exports.[26] The results studying the weight of exports are presented in Appendix Table A6. The point estimates are slightly lower for some specifications, but are very much comparable to our main results.

6 Conclusion

This paper provided empirical evidence of the newly found comparative advantage of U.S. manufacturing following the so-called shale gas revolution. The revolution has led to (very) large and persistent differences in the price of natural gas between the United States and the rest of the world owing to the physical properties of natural gas combined with the distance to foreign markets-energy losses stemming from the liquefaction process alone range from 11-30 percent. Estimation results of gravity models show that U.S. manufacturing exports have grown by about 6 percent on account of

[26] This is computed by summing the Air Shipping Weight, Vessel Shipping Weight and Containerized Vessel Shipping Weight variables in the trade data.

their energy intensity since the onset of the shale revolution. Using a data-set of investment in new and expanding manufacturing plants worth a million dollar and above, we also document that the U.S. shale revolution is operating both at the intensive and extensive margins with new manufacturing sector capacity being added in the energy intensive industries.

From a policy perspective, the shale gas boom has led to a debate in the United States about whether relaxing the restrictions on exporting natural gas would diminish the gains in external competitiveness resulting from lower domestic natural gas prices. The U.S. is indeed expected to join the legion of liquefied natural gas exporters and even become a net exporter of natural gas later this decade according to the U.S. Energy Information Administration (2014). As noted earlier, liquefaction and transportation costs would make exporting liquefied natural gas economical only at relatively high prices prevailing in other markets. The price differential between the U.S. compared to Asia and Europe is thus likely to persist in turn helping lift U.S. manufacturing. Considering the much higher degree of tradability of oil, the removal of restrictions on crude oil exports from the U.S. would be more consequential than for natural gas in making domestic prices higher and in reducing international crude oil prices.

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Tables for Main Text

Table 1: Energy Intensity and Relative Sector Size of Exporting NAICS3 Sectors according to 2002 Input Output Table

Industry	NAICS	Sector Size	Energy Cost		Natural Gas Cost		Labour Cost	
			Total	Direct	Total	Direct	Total	Direct
Food Manufacturing	311	2.36%	4.08%	2.02%	1.87%	0.85%	26.76%	13.59%
Beverage and Tobacco	312	0.62%	2.26%	0.85%	0.94%	0.27%	17.94%	7.54%
Textile Mills	313	0.23%	5.83%	3.26%	2.14%	0.85%	38.18%	21.96%
Textile Product Mill	314	0.16%	3.46%	1.25%	1.34%	0.47%	33.40%	18.68%
Apparel Manufacturin	315	0.21%	3.06%	1.31%	1.72%	0.75%	39.09%	20.54%
Leather and Allied P	316	0.03%	2.62%	1.20%	1.25%	0.52%	37.71%	22.89%
Wood Product Manufac	321	0.46%	3.31%	1.77%	1.23%	0.41%	37.97%	22.91%
Paper Manufacturing	322	0.79%	7.65%	3.82%	4.33%	1.75%	32.68%	18.80%
Printing and Related	323	0.51%	3.00%	1.28%	1.24%	0.29%	47.78%	33.17%
Petroleum and Coal P	324	1.10%	78.21%	66.09%	76.24%	65.31%	12.74%	3.55%
Chemical Manufacturi	325	2.30%	8.33%	3.11%	5.90%	1.63%	28.33%	12.45%
Plastics and Rubber	326	0.88%	4.33%	2.22%	1.56%	0.39%	38.76%	24.85%
Nonmetallic Mineral	327	0.48%	8.38%	4.28%	4.60%	2.06%	40.59%	25.21%
Primary Metal Manufa	331	0.72%	9.15%	4.86%	3.57%	1.55%	36.55%	21.76%
Fabricated Metal Pro	332	1.25%	3.57%	1.56%	1.44%	0.49%	45.85%	29.97%
Machinery Manufactur	333	1.23%	2.27%	0.81%	0.82%	0.19%	44.75%	25.95%
Computer and Electro	334	1.79%	1.73%	0.74%	0.46%	0.13%	42.45%	22.00%
Electrical Equipment	335	0.51%	2.36%	0.97%	0.78%	0.23%	39.41%	23.55%
Transportation Equip	336	3.25%	1.85%	0.63%	0.63%	0.19%	37.99%	18.19%
Furniture and Relate	337	0.38%	2.38%	0.93%	0.77%	0.22%	44.90%	29.23%
Miscellaneous Manufa	339	0.64%	1.80%	0.71%	0.57%	0.15%	41.46%	27.39%

Table 2: Exports by Commodity and Destination Country: Expansion of Energy Intensive Exports

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.238***	0.212***	0.037***	0.223***
$\times$ Price Gap	(0.023)	(0.019)	(0.007)	(0.020)
Clusters	233	233	233	233
Observations	400587	400587	400587	400587
R-squared	.887	.887	.886	.887
Panel B: OECD Regional versus US				
Energy Intensity	0.248***	0.222***	0.033***	0.221***
$\times$ Price Gap	(0.034)	(0.027)	(0.010)	(0.028)
Clusters	86	86	86	86
Observations	175089	175089	175089	175089
R-squared	.901	.901	.901	.901
Panel C: OECD Country versus US				
Energy Intensity	0.258***	0.226***	0.035*	0.220***
$\times$ Price Gap	(0.044)	(0.038)	(0.019)	(0.041)
Clusters	28	28	28	28
Observations	56197	56197	56197	56197
R-squared	.928	.928	.927	.928

Notes: Price Gap is measured as the difference between the relevant destination industrial use price and the US industrial use price. Panel A uses OECD Europe price for all destination countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is the log of the value of exports. All regressions include destination by year fixed effects and destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3: Intensive Margin Exports by Commodity and Destination Country

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.263***	0.246***	0.039***	0.249***
× Price Gap	(0.024)	(0.019)	(0.008)	(0.021)
Clusters	199	199	199	199
Observations	266645	266645	266645	266645
R-squared	.895	.895	.894	.895
Panel B: OECD Regional versus US				
Energy Intensity	0.252***	0.230***	0.031***	0.224***
× Price Gap	(0.037)	(0.031)	(0.011)	(0.033)
Clusters	77	77	77	77
Observations	131683	131683	131683	131683
R-squared	.906	.906	.905	.906
Panel C: OECD Country versus US				
Energy Intensity	0.241***	0.217***	0.024	0.211***
× Price Gap	(0.044)	(0.040)	(0.017)	(0.044)
Clusters	27	27	27	27
Observations	49940	49940	49940	49940
R-squared	.931	.931	.93	.931

Notes: Price Gap is measured as the difference between the relevant destination industrial use price and the US industrial use price. Panel A uses OECD Europe price for all destination countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dataset is constrained to those destination- commodity pairs that reported strictly positive trade throughout the sample period. All regressions include destination by year fixed effects and destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: Extensive Margin Exports by Commodity and Destination Country

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.265***	0.330***	0.179***	0.206***
× Price Gap	(0.086)	(0.074)	(0.033)	(0.070)
Mean DV	.03	.03	.03	.03
Clusters	233	233	233	233
Observations	661487	661487	661487	661487
R-squared	.437	.437	.437	.437
Panel B: OECD Regional versus US				
Energy Intensity	0.134	0.162*	0.110**	0.066
× Price Gap	(0.094)	(0.082)	(0.043)	(0.077)
Mean DV	.03	.03	.03	.03
Clusters	86	86	86	86
Observations	238810	238810	238810	238810
R-squared	.573	.573	.573	.573
Panel C: OECD Country versus US				
Energy Intensity	0.225**	0.239**	0.130**	0.160*
× Price Gap	(0.109)	(0.104)	(0.054)	(0.080)
Mean DV	.03	.03	.03	.03
Clusters	28	28	28	28
Observations	59285	59285	59285	59285
R-squared	.853	.853	.853	.853

Notes: Price Gap is measured as the difference between the relevant destination industrial use price and the US industrial use price. Panel A uses OECD Europe price for all destination countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is a dummy that takes that value of 1 if there is non-zero exports following three consecutive years of no exports and 0 otherwise. All regressions include destination by year fixed effects and destination by product fixed effects. The coefficients are multiplied by 100 for easier exposition. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5: Manufacturing Sector Capital Expenditures at the County Level

	(1) Any	(2) log(Project Count)	(3) log(Investment)	(4) log(Jobs)
Panel A: Total Capital Expenditure				
Energy Intensity	0.109**	0.401*	0.267*	0.401*
× Price Gap	(0.052)	(0.221)	(0.145)	(0.221)
Mean of DV	.0288	.0369	.999	3.01
Clusters	49	49	49	49
Observations	718179	718179	718179	718179
R-squared	.284	.299	.289	.303
Panel B: Capital Expenditure for New Projects				
Energy Intensity	0.066**	0.048**	0.271**	0.236**
× Price Gap	(0.029)	(0.023)	(0.106)	(0.117)
Mean of DV	.0129	.0149	.549	1.38
Clusters	49	49	49	49
Observations	718179	718179	718179	718179
R-squared	.2	.229	.188	.208

Notes: Panel A uses total Capital Expenditure, which includes capacity expansions and completely new capacity. Panel B only uses completely new capacity. The Price Gap is measured as the price difference between OECD Europe and the US industrial prices. Coefficients are multiplied by 100 for better exposition. All regressions control for state-by-year fixed effects and county by industry fixed effects. Column (1) is a linear probability model if there is any investment, column (2) uses the log of the number of projects per county and industry, while column (3) uses the log of investment amount in millions of US dollars. Column (4) uses the log of the total number of jobs created. Standard errors are clustered at the state level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6: Energy Intensity and Export Growth : Estimated Effects at the 3 digit Sector Level

NAICS	Label	Energy Cost Share	Share of Exports	Estimate	SE	
312	Beverage and Tobacco	2.26%	0.54%	-0.022	0.021	
313	Textile Mills	5.83%	0.68%	-0.048	0.014	***
314	Textile Product Mill	3.46%	0.23%	-0.031	0.011	**
315	Apparel Manufacturin	3.06%	0.24%	-0.010	0.013	
316	Leather and Allied P	2.62%	0.22%	-0.029	0.014	**
321	Wood Product Manufac	3.31%	0.47%	-0.020	0.022	
322	Paper Manufacturing	7.65%	1.94%	0.016	0.018	
323	Printing and Related	3.00%	0.47%	-0.040	0.018	**
324	Petroleum and Coal P	78.21%	8.73%	0.097	0.020	***
325	Chemical Manufacturi	8.33%	14.92%	0.038	0.020	*
326	Plastics and Rubber	4.33%	2.27%	0.033	0.018	*
327	Nonmetallic Mineral	8.38%	0.80%	0.003	0.017	
331	Primary Metal Manufa	9.15%	5.88%	0.047	0.021	**
332	Fabricated Metal Pro	3.57%	3.18%	0.040	0.021	*
333	Machinery Manufactur	2.27%	12.48%	0.022	0.027	
334	Computer and Electro	1.73%	9.79%	-0.056	0.020	**
335	Electrical Equipment	2.36%	2.93%	0.007	0.022	
336	Transportation Equip	1.85%	10.53%	0.006	0.027	
337	Furniture and Relate	2.38%	0.39%	-0.003	0.016	
339	Miscellaneous Manufa	1.80%	3.48%	0.011	0.019	

Notes: Table presents NAICS3 sector specific effect of US to OECD regional gas price differences on sector specific exports. The coefficients are semi-elasticities, indicating the % change in exports for a commodity if the price gap increases by one USD. The Energy Cost Share is the total energy consumed based on input-output tables, directly via all main sources of primary energy and indirectly, through intermediate goods. Share of Exports presents the relative size of a sector in terms of overall export share for the period before 2005.

Table 7: Energy Intensity and Export Growth: Interaction Effects with Other Sector Characteristics

	(1)	(2)	(3)	(4)
Energy Intensity	0.238***	0.229***	0.228***	0.205***
× Price Gap	(0.023)	(0.023)	(0.023)	(0.023)
Capital Intensity		-0.062***		-0.082***
× Price Gap		(0.011)		(0.011)
Labor Intensity			-0.037***	-0.076***
× Price Gap			(0.014)	(0.015)
Clusters	233	233	233	233
Observations	400587	400587	400587	400587
R-squared	.887	.887	.887	.887

Notes: Estimating heterogenous effects by other factor intensities. The Price Gap is computed as the gap between US industrial use natural gas prices and OECD region specific industrial use natural gas prices. Details on the computation of Energy- , Capital and Labor intensity are provided in Appendix A.2. Standard errors are clustered at the destination country with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A Appendix

A.1 Trade Data

This part of the appendix describes how the trade data of Schott (2008) was processed to construct two data sets that are used in this paper. The two data sets are: (1) a balanced panel of trade between the US and partner countries at the five digit sector code level and (2) an unbalanced panel of trade between US customs districts and trade partner countries at the five digit sector code level.

In order to arrive at the second data set, some processing of Schott (2008) data is necessary. The data are provided at the harmonised system (HS) product code classification for trade data. The trade data have four panel dimensions: origin or destination US customs district c, product code j, and origin or destination country i in year t.[27] The product codes j data are mapped to 7-digit North American Industry Classification Codes (NAICS) using the routine detailed in Pierce and Schott (2012a). As the Input-Output tables are computed using combined NAICS codes for several sectors, we map the 7 digit NAICS sectors to 5 digit NAICS sectors, by aggregating import- and export flows on the panel identifiers i, c, t and the transformed 5 digit product code j. In total, there are 167 NAICS5 sectors, 18 years of data, 233 of countries with which the US trades and 44 US customs districts.

The result of this collapse is the second data set that is used for robustness to highlight, that the within-US price variation in natural gas prices does not add a significant dimension to the analysis. The data set has roughly 4 million observations, but is highly unbalanced as there are many US customs districts that do not trade with other countries for certain product codes. A balanced panel would consist of around 167 x 18 x 233 x 44 = 30.8 million observations, out of which only these 4 million observations are zero.

The main data set used in the analysis removes the US customs district dimension by collapsing the data. This makes the data set a lot more manageable with only 167 x 18 x 233 = 700,398 observations.

A.2 Energy Intensity from Input-Output Tables

We use the approach discussed in Fetzer (2014) to construct the energy intensity of the five digit industries using the 2002 Bureau of Economic Analysis Input-Output table. The input-output use table provide for each industry, a break-down of all direct costs by commodity that the industry incurs to achieve its level of output.

The direct energy cost is computed as the sum of the costs that an industry incurs using direct energy commodities. Energy commodities are considered to be those produced by the following following six digit NAICS industries:

[27] I refer to product and sector codes j interchangably.

NAICS 6	Industry Name
211000	Oil and gas extraction
221100	Electric power generation and distribution
221200	Natural gas distribution
486000	Pipeline transportation
S00101	Federal electric utilities
S00202	State electric utilities

Table A1: Input Output Table Direct Natural Gas Consumption

Unfortunately, the Oil and gas extraction sector is not further decomposed into natural gas- or oil extraction, which adds some noise to the measurement. Nevertheless, the table provides all direct energy consumption and captures the three ways that natural gas can be consumed. The three ways to consume natural gas directly follow from the deregulation of the industry which ultimately separated natural gas extraction from transportation. This was achieved in a lengthy regulatory process, beginning with the Natural Gas Policy Act of 1978, and subsequent Federal Energy Regulatory Commission (FERC) orders No. 436 in 1985 and 636 in 1992. These orders ultimately separate the extraction from the transportation process, mandating open access to pipelines which allows end-consumers or local distribution companies (LDCs) to directly purchase natural gas from the producers.

The three ways natural gas is (purchased) for consumption are:

1. Direct Purchases from the Oil and Gas Extraction Sector, in addition to costs for Pipeline Transportation (NAICS 211000, 486000).

2. Indirect Purchases Through Natural Gas Distribution Utilities (NAICS 2212000 and 486000).

3. Indirect Purchases Through Electric Utilities using natural gas for power generation (NAICS 2211000, S00101 and S00202).

Now, we can further refine this as natural gas is also indirectly consumed through the value chain in form of intermediate products. In order to account for this indirect consumption, we perform the above step iteratively. Since we know the energy cost share for each commodity, we can compute the energy cost component of each intermediate input and simply add these costs up. This allows us to compute the indirect energy cost share.

We proceed in the same way to compute the labor cost share. In the input-output table, each sector reports its labor costs. We simply compute the direct and indirect labor cost share using the same method.

Last, but not least, we compute Capital Intensity of a sector. We follow the approach in Acemoglu and Guerrieri (2006), who construct capital intensity of a sector as:

$$K_j = \frac{VA_j - W_j}{VA_j}$$

where VA_j is nominal value added in sector j and W_j is the wage bill of that sector. The three components of value added are (1) compensation of employees, (2) taxes on production and imports less subsidies, and (3) gross operating surplus.

The resulting time invariant measures are merged with the trade data. For some sectors, we have to compute the energy intensity at a four digit level, as the NAICS codes in the input output tables combine several sector codes or are only available at the four digit sector level.

A.3 Exploiting Within-US Natural Gas Prices

As highlighted in Fetzer (2014), the shale gas boom has lead to some price discrepancies within the US, which are partly due to a lack of physical pipeline capacity, but also due to high transport costs within pipelines over long distances. These transport costs are however, very small, in comparison to the transport costs when considering shipping natural gas as LNG. Nevertheless, we explore here whether within-US price differences provide dramatically different estimates as compared with the main results in the paper.

We do so by performing the same regressions as in the main Table 2, except that we retain the US customs district dimension as described in Appendix A.1. We map Industrial use natural gas price data with the unbalanced panel. The industrial use natural gas price data was obtained from the Energy Information Administration (EIA) and is available at the state-level from 1997 onwards. When doing this map, we make a strong assumption, that the US origin customs district is also the location of production or consumption for the goods that are exported or imported.

We estimate very similar specifications:

$$X_{ijct} = \alpha_{ict} + b_{ijc} + \gamma \times E_j \times \Delta P_{ct} + \epsilon_{ijct} \tag{6}$$

excpet that now the unit of observation also has the US customs district c dimension. As before, the fixed effects α_{ict} control trade-pair time effects that are not sector specific (such as exchange rates). The other demand shifters b_{ijc} also add the US customs district dimension. Most importantly, we can now adjust our measure for the price gap P_{ct}, to account for the price differences across US customs districts.

The results from this regressions are presented in Table A2.

Online Appendix Tables and Figures

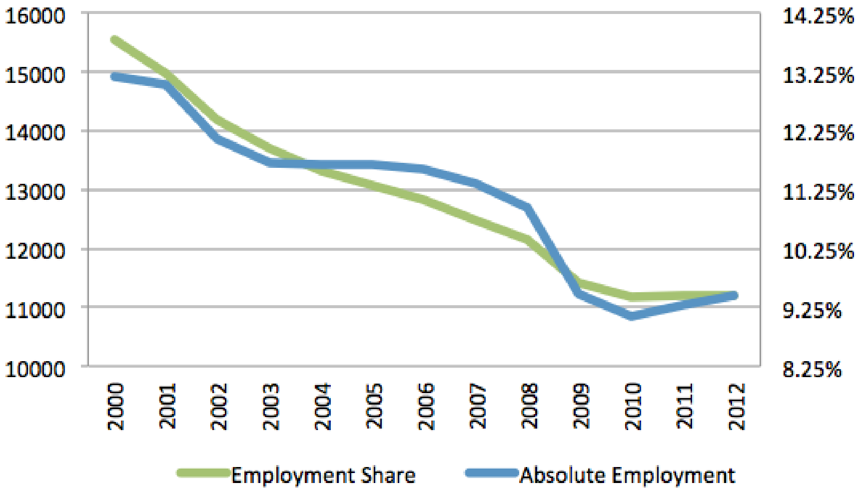

Figure A1: Share and Absolute Size of Manufacturing Sector Employment

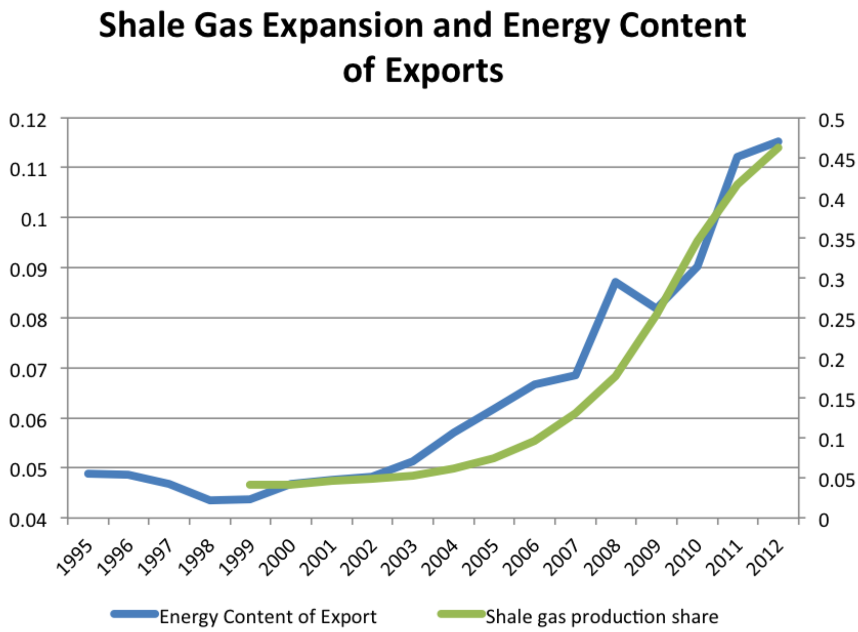

Figure A2: Energy Content of US exports and expansion of shale gas production as a share of overall dry natural gas production in the US.

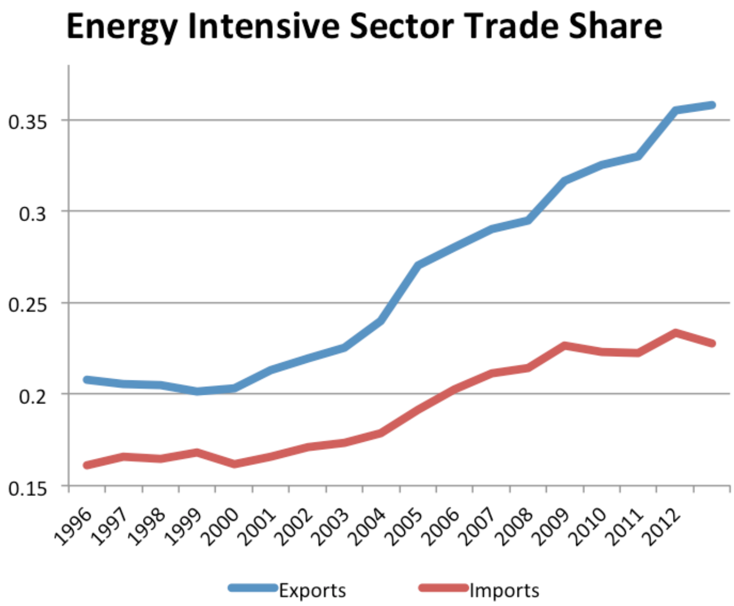

Figure A3: Share of Overall Exports or Imports of Energy Intensive Sectors. Classified as Energy Intensive are 3 digit sectors 324, 325, 326, 327, 331 and 332.

Table A2: Exports by US Customs District, Commodity and Destination Country: Expansion of Energy Intensive Exports

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.164***	0.146***	0.036***	0.151***
$\times$ Price Gap	(0.014)	(0.012)	(0.005)	(0.012)
Clusters	233	233	233	233
Observations	2534603	2534603	2534603	2534603
R-squared	.775	.775	.775	.775
Panel B: OECD Regional versus US				
Energy Intensity	0.106***	0.097***	0.018***	0.097***
$\times$ Price Gap	(0.018)	(0.015)	(0.006)	(0.016)
Clusters	86	86	86	86
Observations	1492881	1492881	1492881	1492881
R-squared	.784	.784	.784	.784
Panel C: OECD Country versus US				
Energy Intensity	0.113***	0.103***	0.013	0.105***
$\times$ Price Gap	(0.028)	(0.024)	(0.008)	(0.026)
Clusters	28	28	28	28
Observations	686279	686279	686279	686279
R-squared	.813	.813	.813	.813

Notes: Price Gap is measured as the difference between the relevant US customs district industrial use natural price and the relevant destination industrial use price. Panel A uses OECD Europe price for all destintation countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is the log of the value of total exports. All regressions include destination by year fixed effects and US customs district origin by destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A3: Effect on Export Levels by Commodity and Destination Country

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	45.294***	32.554***	6.799***	37.063***
× Price Gap	(11.348)	(8.119)	(1.823)	(9.268)
Mean DV	18.36	18.36	18.36	18.36
Clusters	233	233	233	233
Observations	661487	661487	661487	661487
R-squared	.833	.832	.831	.833
Panel B: OECD Regional versus US				
Energy Intensity	37.640***	27.090***	4.982***	30.589***
× Price Gap	(14.175)	(9.891)	(1.855)	(11.412)
Mean DV	38.66	38.66	38.66	38.66
Clusters	86	86	86	86
Observations	238810	238810	238810	238810
R-squared	.853	.853	.852	.853
Panel C: OECD Country versus US				
Energy Intensity	84.077**	61.373**	11.313**	67.818**
× Price Gap	(37.705)	(26.346)	(5.242)	(30.577)
Mean DV	118.24	118.24	118.24	118.24
Clusters	28	28	28	28
Observations	59285	59285	59285	59285
R-squared	.87	.87	.869	.87

Notes: Price Gap is measured as the difference between the relevant destination industrial use price and the US industrial use price. Panel A uses OECD Europe price for all destination countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is the level of the value of exports. All regressions include destination by year fixed effects and destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A4: Effect on Log(Imports) by Commodity and Country Imports: No Discernible Effect on Imports

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.030	0.048*	-0.043***	0.052**
× Price Gap	(0.031)	(0.026)	(0.013)	(0.026)
Clusters	233	233	233	233
Observations	231493	231493	231493	231493
R-squared	.9	.9	.9	.9
Panel B: OECD Regional versus US				
Energy Intensity	-0.004	0.006	-0.039**	0.023
× Price Gap	(0.037)	(0.033)	(0.017)	(0.032)
Clusters	86	86	86	86
Observations	129849	129849	129849	129849
R-squared	.905	.905	.905	.905
Panel C: OECD Country versus US				
Energy Intensity	-0.017	-0.023	-0.026	0.009
× Price Gap	(0.044)	(0.043)	(0.022)	(0.040)
Clusters	28	28	28	28
Observations	53951	53951	53951	53951
R-squared	.916	.916	.916	.916

Notes: Price Gap is measured as the difference between the relevant import origin industrial use price and the US industrial use price. Panel A uses OECD Europe price for all origin countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is the log of the value of imports. All regressions include origin by year fixed effects and destination by product fixed effects. The coefficients are multiplied by 100 for easier exposition. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A5: Effect on Extensive Margin to Import by Commodity and Country

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	-0.018	0.149**	-0.056	0.065
$\times$ Price Gap	(0.090)	(0.075)	(0.036)	(0.078)
Mean DV	.05	.05	.05	.05
Clusters	233	233	233	233
Observations	661487	661487	661487	661487
R-squared	.284	.284	.284	.284
Panel B: OECD Regional versus US				
Energy Intensity	-0.101	0.056	-0.015	-0.001
$\times$ Price Gap	(0.109)	(0.097)	(0.055)	(0.101)
Mean DV	.06	.06	.06	.06
Clusters	86	86	86	86
Observations	238810	238810	238810	238810
R-squared	.399	.399	.399	.399
Panel C: OECD Country versus US				
Energy Intensity	-0.148	0.028	0.123	-0.002
$\times$ Price Gap	(0.268)	(0.218)	(0.091)	(0.217)
Mean DV	.06	.06	.06	.06
Clusters	28	28	28	28
Observations	59285	59285	59285	59285
R-squared	.768	.768	.768	.768

Notes Notes: Price Gap is measured as the difference between the relevant origin industrial use price and the US industrial use price. Panel A uses OECD Europe price for all origin countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is a dummy that takes that value of 1 if there is non-zero imports following three consecutive years of no imports and 0 otherwise. All regressions include destination by year fixed effects and destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A6: Effect on Export Weight by Commodity and Destination Country

	All Energy Inputs		Natural Gas Input	
	(1)	(2)	(3)	(4)
	Direct	Direct + Indirect	Direct	Direct + Indirect
Panel A: OECD Europe versus US				
Energy Intensity	0.167***	0.181***	0.036***	0.182***
× Price Gap	(0.025)	(0.021)	(0.009)	(0.022)
Clusters	233	233	233	233
Observations	398068	398068	398068	398068
R-squared	.848	.848	.848	.848
Panel B: OECD Regional versus US				
Energy Intensity	0.177***	0.198***	0.013	0.180***
× Price Gap	(0.029)	(0.024)	(0.013)	(0.024)
Clusters	86	86	86	86
Observations	173706	173706	173706	173706
R-squared	.857	.857	.857	.857
Panel C: OECD Country versus US				
Energy Intensity	0.160***	0.180***	0.012	0.156***
× Price Gap	(0.034)	(0.034)	(0.026)	(0.037)
Clusters	28	28	28	28
Observations	55970	55970	55970	55970
R-squared	.872	.872	.872	.872

Notes: Price Gap is measured as the difference between the relevant origin industrial use price and the US industrial use price. Panel A uses OECD Europe price for all origin countries. Panel B uses computed OECD regional prices where available. Panel C restricts the sample to include only OECD countries with price data available. The dependent variable is the log of total export weight in tons. All regressions include destination by year fixed effects and destination by product fixed effects. The Energy Intensity measure used in columns (1) and (2) focus on all types of energy consumed, while the measure used in columns (3) and (4) focus on natural gas consumption. Columns (1) and (3) use only direct energy consumption, while columns (2) and (4) also includes indirect energy input through intermediate goods. Standard errors are clustered at the destination country level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A7: Manufacturing Sector Capital Expenditures by County and Industry - Restricting to Counties not on Shale Deposits

	(1) Any	(2) log(Project Count)	(3) log(Investment)	(4) log(Jobs)
Panel A: Total Capital Expenditure				
Energy Intensity	0.070	0.401*	0.142	0.253
× Price Gap	(0.052)	(0.221)	(0.136)	(0.229)
Mean of DV	.0288	.0369	.999	3.01
Clusters	49	49	49	49
Observations	545622	718179	545622	545622
R-squared	.263	.299	.271	.278
Panel B: Capital Expenditure for New Projects				
Energy Intensity	0.046*	0.033	0.195**	0.160
× Price Gap	(0.027)	(0.023)	(0.089)	(0.115)
Mean of DV	.0129	.0149	.549	1.38
Clusters	49	49	49	49
Observations	545622	545622	545622	545622
R-squared	.192	.22	.184	.199

Notes: Dataset is restricted to only include counties that do not have shale deposits. Panel A uses total Capital Expenditure, which includes capacity expansions and completely new capacity. Panel B only uses completely new capacity. The Price Gap is measured as the price difference between OECD Europe and the US industrial prices. Coefficients are multiplied by 100 for better exposition. All regressions control for state-by-year fixed effects and county by industry fixed effects. Column (1) is a linear probability model if there is any investment, column (2) uses the log of the number of projects per county and industry, while column (3) uses the log of investment amount in millions of US dollars. Column (4) uses the log of the total number of jobs created. Standard errors are clustered at the state level with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.